TITLE: Telepresence and Intervention Robotics

TELEPRESENCE AND INTERVENTION ROBOTICS

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ABSTRACT

In the field of Mobile Robotics applications dedicated to inspection or intervention in hostile, unreachable or unstructured environments, human operators are "processed" in the control loop developed for a Telepresence System. On the one hand dynamic situations suffer from a lack of automation degree by mobile robots but on the other hand a complete task robotisation can run counter to economic or human constraints. In mine clearance activity for instance, mobile robots and especially teleoperated semi-legged robots can be seen as a solution, not to replace the mine clearance specialists, but as a safe tool for human operators in some well-defined situations.

As human interaction with a machine is often oriented towards application, the teleoperation of a mobile robot under geometrical constraints is not easy to achieve if no training period occurred previously for the operator. A footbridge exists between training and relevant missions on navigation tasks: a real activity with a mobile robot can be prepared in a micro-world – a virtual world or an Augmented Reality world.

But the use of Telepresence systems, presented here as destined for an inescapable expansion because of cultural yearning with ancestral roots, is submitted to human factors. In this paper, after a discussion about the ubiquity myth in Telepresence, we present a Telelocomotion system with a Control-Command-Communication (C3) strategy adapted in a Service and Intervention context to semi-legged robots like our RAMSES (French acronym for Mobile Autonomous Robot with an Advanced Support System). The vision aspect is focused on and vision sickness issues generated by the motion of visual feedback are analysed. Some solutions to avoid or diminish troubles with either an appropriate camera or specific control laws are presented. Experiments are in progress to study the relevance in Telelocomotion of a Behavioural Transform by means of gestures produced by a dedicated optical fibre glove to operate a legged robot in comparison with the use of a joystick.

INTRODUCTION

In the field of Mobile Robotics applications dedicated to inspection or intervention in hostile, unreachable or unstructured environments, human operators are "processed" in the control loop developed for a Telepresence System. On the one hand, dynamic situations suffer from a lack of automation degree by mobile robots, but on the other hand, a complete task robotisation can run counter to economic or human constraints. In mine clearance activity for instance, mobile robots and especially teleoperated semi-legged robots can be seen as a solution, not to replace the mine clearance specialists but as a safe tool for human operators in some well-defined situations.

Different investigations are possible when dealing with legged robots and dedicated tasks. At the L.R.P. (Laboratoire de Robotique de Paris), we focus our attention on problems related to the stability of quadruped robots with a "force control and distribution" approach [Nak.89] [Kim.90]. Currently we study legged robots with respect to various situations (different topologies, rough terrain, partially unknown environments). Such an aim requires matching the task to be accomplished and the mechanical specifications of the robot. We have observed in many cases that hybrid structures (e.g., legs plus wheels) [Vil.93] [Fon.94a] are very well adapted to navigation tasks in some ways like stability (i.e., teleoperation is facilitated if the general instability of the robot is overcome).

As human interaction with a machine is often oriented towards application, the teleoperation of a mobile robot under geometrical constraints is not easy to achieve if no training period occurred previously for the operator. A footbridge exists between training and relevant missions on navigation tasks: a real activity with a mobile robot can be prepared in a micro-world – a virtual world or an Augmented Reality world.

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But the use of Telepresence systems, presented here as destined for an inescapable expansion because of cultural yearning with ancestral roots, is submitted to human factors. In this paper, after a discussion in the first section about the ubiquity myth in Telepresence, we present in the second section a Telelocomotion system with a Control-Command-Communication (C3) strategy adapted in a Service and Intervention context to semi-legged robots like our RAMSES (French acronym for Mobile Autonomous Robot with an Advanced Support System). The vision aspect is focused on and vision sickness issues generated by the motion of the visual feedback are analysed. Some solutions to avoid or diminish troubles with either an appropriate camera or specific control laws are presented. Experiments are in progress to study the relevance in Telelocomotion of a Behavioural Transform by means of gestures produced by a dedicated optical fibre glove to operate a legged robot in comparison with the use of a joystick. These experiments are described in the third section.

TELEPRESENCE

Introduction

In French language dictionaries the « Telepresence » neologism is not yet referenced. However, more and more researchers and manufacturers take an interest in Telepresence. This first section deals with ubiquity and myths becoming Virtual Reality in order to try to explain the inescapable expansion of Telepresence.

Ubiquity

« Ubiquity Society »

According to Jean Cazeneuve, a contemporary French sociologist, we are a « ubiquity society » [Caz.70] [Alb.95], resting on audio-visual media, extraordinarily rapid diffusion of hertzian waves adding an almost instant-dimension to its universal nature. Does that mean that people daily apprehend media with ubiquity characteristics and that it is possible to be present in several places at the same time?

In any case, this is the viewpoint of several contemporary researchers. Media like printed matter, painting reproductions, disks, and most of all *telematic networks, and information highways,* are said to allow ubiquity in works of art and information [Asc.97]. As early as 1928, Paul Valéry, in a visionary text [Val.28], was considering « a sort of ubiquity » for works of Art, imagining a future home-distribution with techniques from a so-called « Sensitive Reality » without anything less than what is called today « Virtual Reality ». Moreover, there ar many c who consider that going on the air, on television, speaking on the phone, are many ways to have a certain type of ubiquity [Alb.95] [Bal.95].

But is it right to talk about ubiquity in these cases?

« Corporal Ubiquity » and « Virtual Ubiquity »

Most adult human beings have an image of themselves, from their bodies [Sch.68] [Cor.72], that causes them to understand that the type of ubiquity we designate as « corporal » is unrealistic: except in some primitive tribes and among some heautoscopic trouble-related illnesses, the mirror image is just an image of the proprioceptive body. Our human condition and our world perception do not permit considering ubiquity in any other way than the « corporal ubiquity ». Now it is no more possible to be the same human being in several identical bodies, than to exist in several places at the same time, acting differently on the environment in different places (or in one place) like Marcel Aymé's heroine in its short story Les Sabines [Aym. 43].

Going on the air, on television, speaking on the phone, is the option to be « virtually ubiquitous ». Only a voice « image » is transmitted quasi-instantaneously, then is presented in several places, though the direct voice and the real body that produces this voice exists in only one place.

Mythology and Theology

The « immemorial ubiquity dream » [Bal.95] of man, namely « corporal ubiquity », appeared in mythology and theology: the Brahman [Ind.95] [Sid.95] and Greek pantheons [Pyt.95] had the fanciful gift well before the monotheist religions initiated the ubiquity dogma [Bre.95] [Dum.95]. If the pluri-presence[2], and precisely « virtual ubiquity » can be considered for human beings thanks to brand new technologies like Virtual Reality, the pluri-existence is and will be reserved to gods: the Visnu avatars and the Trinity are a few examples. Jean-Paul Papin sums up the discussion as follows [Pap.97]:

« Ubiquity is to presence what Trinity is to existence »

Trinity deals with several beings being together, that « are » and « exist », though ubiquity deals with the same being, present in several places at the same time.

Telepresence and «Quasi Corporal Ubiquity»

Then, is it right to speak about ubiquity – meaning "corporal ubiquity" – in Telepresence?

« Quasi Corporal Ubiquity »

We have tried to demonstrate that « virtual ubiquity » is possible by means of a hardware and software interface. Then to be able to talk not only about Telepresence but also about « quasi corporal ubiquity » it is sufficient to have at one's disposal:

- A control-command-communication software and hardware architecture that allows one to have a distant image of oneself, which is mobile and controlled with a one-to-one relation,
- Sensorial feedback, sufficient to give the impression of immersion in a distant, real environment, because of the previous architecture,
- Physical action abilities in this environment.

It is only in the situation where the operator action has an effect in a world where he is supposed to be, that Telepresence can be talked about.

Robot Concept

The mobile robot is an operator image as the operator himself is in God's own image in Judaeo-Christian tradition. It has its own future in case of operator/teleoperator interface malfunction.

The robot concept dates back to ancestral desires. The Hephaistos god, in Greek mythology, built some obedient voice-operated « tripods » to help him with his forging work. It was only in the '20's that some « little artificial anthropomorphic beings perfectly obedient to their masters » were designed for the first time, designated by the term « robot », in a play called « R.U.R. » (Rossom's Universal Robot) [Tsc.20][Coi.82], by the Czech Karel Tschapek.

If the Oxford dictionary defines the robot as follows: « a mechanical apparatus resembling and doing the work of a human being », it is not well accepted even in the '80's because « no existing and useful robot is alike human » [Coi.82] at this time. Nowadays, the expansion of biped, quadruped or hybrid mobile robots validates the robot formal definition especially if it is brought together with the Sagittarius concept [Fon.95].

Sagittarius Concept

A mythical creature illustrates the « quasi corporal ubiquity »: the Sagittarius. It is particularly interesting to point out that a human operator can be directly superimposed on a robot. For that, we need to see the human locomotion and the gripping actions as the exact replica of what can be done by the front part of an antic creature: a Sagittarius (Figure 1).

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[2] Presence in many places at the same time

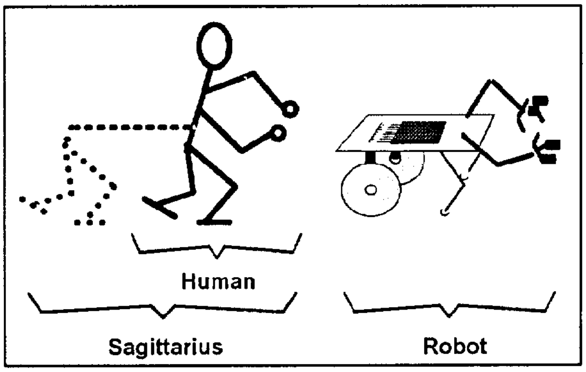

Figure 1. Morphologic Equivalence Between a Human, a Sagittarius and a Robot

It is also referred to as the mythical creature, half a man and half a horse, called a Centaur. The Sagittarius' humanoid upper human body is dedicated to gripping and sensitive functions, it holds a bow (a tool!). The locomotive lower body comes from a horse.

A one-to-one relation exists between the operator (the Sagittarius) and the teleoperator (the robot). The rear parts of the robot and the Sagittarius tend to improve the teleoperator stability and are totally controlled by the front part: the rear of the horse corresponds to the robot part that follows the "Leader". In our case, the wheels placed at the rear provide the global stability of the system without the contribution of the human "virtual" rear legs. The leaders are in the front and are directly operated by the operator's legs.

TELELOCOMOTION SYSTEM

Semi-Legged Robot

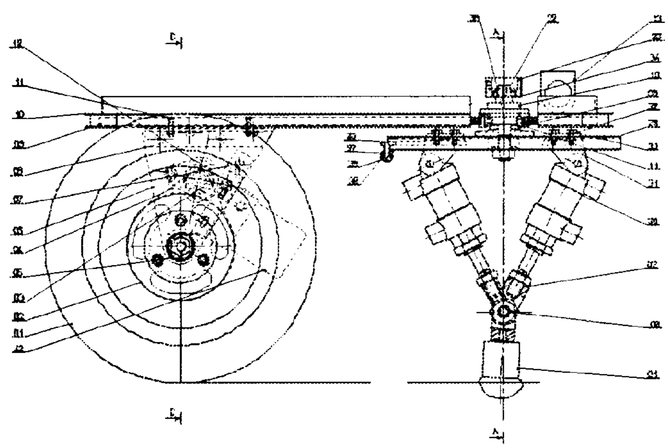

Figure 2. Layout of RAMSES IIb.

We developed a mini semi-legged mobile robot called RAMSES IIb based on RAMSES and RAMSES II presented in [Fon.94b][Cis.95]. This robot has front pneumatic legs and powered wheels at the rear for better support (wheels placed in Gordini way) (Figure 2).
It is able to walk (and roll) in an automatic or teleoperated mode to achieve what is called *Telelocomotion* [Khe.95]. This type of robot affords a quasi-unconditional stability and has been designed keeping in mind small obstacle avoidance under teleoperation routines.

It is necessary to teleoperate the robot with the most direct relation between the operator and the mobile robot in order to provide an ergonomic human-robot interface. For that, we need the one-to-one relation given by the Saggitarius concept (Figure 1).

In order to facilitate the development of a demonstrator, two operator fingers are equipped, instead of his legs: the movement is produced by an optical fibre-based dataglove called *LightGlove©* (Figure 3) that we especially developed for this application, which covers the hand of the operator. The robot legs copy the operator fingers [Fon.94a] [Fon.94b] [Khe.95] [Fon.95] [Cis.95].

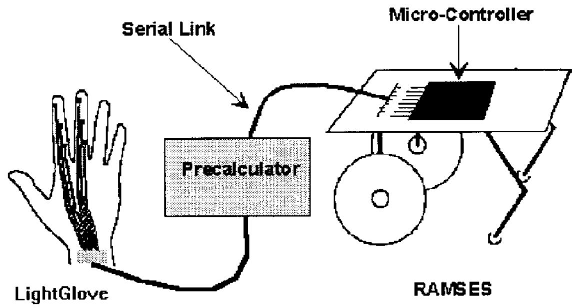

Figure 3. Legs Control with the Fingers.

Obviously, a very efficient way to teleoperate a system can be a Telepresence system which uses modern tools (e.g. Virtual Reality), and as far as possible direct relations between human abilities (physical and psychological) and the robot's characteristics.

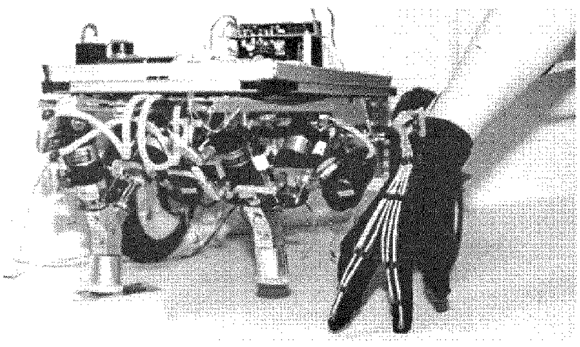

Figure 4. RAMSES IIb and the LightGlove©

TELELOCOMOTION DEVICES

During the teleoperation mode, the operator is fitted out with a two-finger LightGlove©. The robot speed is controlled directly by the finger flexion speed. For visual feedback, the operator is assisted by a method which keeps his hands free. The environment is re-created in conjunction with *virtual cameras* fixed to the robot or according to the choice of the operator.

The robot direction is determined according to the yaw of the arm's proximal part around a fixed (vertical) axis through the forearm. The command is eased by a special cradle, the main component of the telelocomotion device presented in [Fon.95]. However, it may appear that the ergonomic constraints taken into consideration for the development of this device would not be sufficient to assure a global physico-psychological comfort to the operator.

VISION SYSTEM FOR TELELOCOMOTION

D. Ernadotte and S. Neuman [Ern.94] asserts that, during Telepresence, « it is important to have a general view of a scene and more precise views for manipulations ». From the two types of tasks to execute (*navigation* and *mission*), we classified two sorts of video systems embedded in the telelocomotion system [Cis.96]:

- A long distance video system, allowing the operator to locate the robot in its environment,
- A precise video system, efficient at a short distance, for sharp missions (inspection, obstacle avoidance, fine object manipulation with a gripping device).

D. McGovern [Gov.93] gives experimental results about several types of video equipment on mobile wheeled robots with different architectures, on very unstructured grounds with obstacles: *positives* (bumps) or *negatives* (holes).

To determine the appropriate video system for each of the two types of tasks mentioned above, we studied [Gov.93] and synthesised the results of experiments about video systems on teleoperated all-terrain wheeled robots.

Navigation

In navigation, our concern is with robots that can be piloted:

- Out of visual reach,
- Or into the operator's visual field.

The out of visual reach Telelocomotion requires an embedded video system. It is called « inside-out » teleoperation [Gov.95] with an « eye of snail » vision [Pap.95].

But when the mobile robot is in the operator's visual field, the pilot sequences may be achieved:

- Either directly, with an "eye of God" view [Pap.95],
- Or in the same conditions as in out of visual reach, only with the "eye of snail" view,
- Or semi-directly by means of a video system located on another robot we called "relay robot". In the mine clearance activity, robots of different sizes and velocities step in: a main robot can be accompanied by little, simple and very quick robots it supervises, whereas the others examine closely the suspicious objects.

In the case of a unique semi-legged robot to teleoperate the solution we propose for navigation is an embedded video system. In order to allow the location of the robot in its environment, it is necessary to have a *periscope* type device with a 360° visual field.

However, additional direct or semi-direct information does not have to be excluded when available. The visual information fusion, performed by the operator, can avoid some incidents listed by [Gov.93]:

- Roll-overs in « inside-out teleoperation »,
- Frequent collisions with obstacles in "outside-in teleoperation".

During navigation, a black and white camera can be sufficient. However, it can be useful to discriminate surfaces merged in black and white (a road and its sides for instance), and therefore is preferred a colour camera.

It must be noted that with a quick robot, rounding bends is easier when a camera rotation allows anticipating the curve to follow [Per.94]. This anticipation is feasible with a camera directional control on:

- Either the glance direction [Per.94],
- Or the legs' direction.

Mission

In the case of a video system dedicated to missions, it is interesting that colour is preferred for better detection of objects and obstacles.

D. Ernadotte et al. [Ern.94] conclude from a series of experiments that automatic systems of convergence and autofocus must be added on stereoscopic visions. We think that these devices are appropriate, but we stress the fact that they must be disconnectable by the operator during the task.

VISION SICKNESS

A vision system, even well-adapted to the task to execute, can generate troubles if it is placed on a mobile platform.

From previous studies, and especially from [Oma.93], it appears that: « "Motion Sickness" is the general term describing a group of common nausea syndromes originally attributed to motion-induced cerebral ischemia, stimulation of abdominal organ afferent, or over-stimulation of the vestibular organs of the inner ear. Sea-, car- and air-sickness are the most commonly experienced examples. However, the discovery of other variants such as Cinerama-, flight simulator-, spectacle-, and space- sickness in which the physical motion of the head and body is normal or absent has led to a succession of "sensory conflict" theories which offer a more comprehensive etiologic perspective. Implicit in the conflict theory is the hypothesis that neural and/or humoral signals somehow traverse to other centres mediating sickness symptoms. »

We propose to reduce the general term *Motion Sickness* to *Vision Sickness* [Cis.96] when it deals with symptoms due to a sensory conflict between visual stimuli from a picture in motion (provided for instance by a real or virtual scene on a screen) and a normal (or absence of) kinaesthetic feeling. Vision Sickness may then accompany every system with real or virtual visual feedback.

In our telepresence system, visual feedback can provide vision sickness in three ways, corresponding to the three degrees of freedom (DOF) of a vision system placed on the platform of a semi-legged robot: pitch, roll and yaw.

Pitch Sickness

The most obvious sickness is associated with the pitch generated by the robot pneumatic leg height variations during a walking cycle [Khe.95]. At high velocity, the fuzzy and jerky visual feedback is as unusable as uncomfortable.

Roll Sickness

Though the roll is suppressed by the wheels at the rear on a flat terrain, it still exists on a very unstructured ground on which our robot is mainly dedicated to be teleoperated. This DOF may independently provide this type of discomfort.

Yaw Sickness

The last (but not the least) DOF sickness may be generated by a mismatch between the video system yaw and the robot direction changes or between the video system yaw and the kinaesthetic way it is operated: P. Peruch, at the end of his presentation of [Per.94], put forward an additional commentary about operators sickness provided when a 1-to-2 ratio exists between a head yaw controlling the direction of a virtual robot and the robot gaze direction, in order to give a better anticipation of a curve. This disorientation, obviously due to a sensory conflict, is our concern when using a periscope camera and must induce the camera command choice.

SOLUTIONS TO AVOID VISION SICKNESS

We propose different solutions (the list is non-exhaustive) to avoid each type of vision sickness in our telepresence systems. Our study takes a range of grounds and gaits into account: the best solution depends on the telelocomotion nature. Solutions are gathered according to the DOF on which they act.

Tilt Sickness Avoidance

The tilt ε due to the pitch phenomenon of the platform (the "back" of the robot) is represented in Figure 5. In order to suppress pitch sickness, it is possible to intervene at least at three stages:

- Obviously, to avoid the pitch of the robot when it walks it is possible to keep α and ε constant. This tilt can be minimised (at least completely compensated) as described in [Khe.95], by reducing the attainable domain of the legs' ends given an intermediary platform height, with controlled pneumatic jacks' lengths. Therefore, this solution is efficient in a flat terrain but has disadvantages on a very unstructured one: the leg height compensation unfortunately leaves the variations due to the terrain unchanged.

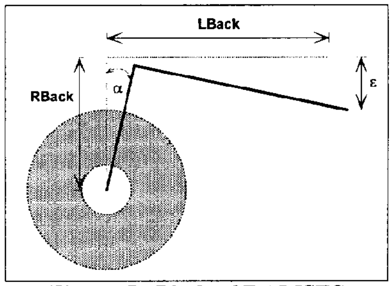

Figure 5. Pitch of RAMSES

- In a similar way a controlled camera platform can compensate the tilt with an identical ε, not restraining the leg attainable domain. This solution can directly use the results of [Ber.96]: it deals with an anthropoid stereoscopic foveated vision system with 4 DOF, 2 for its head motion and 2 for its eyes motion: « The Vestibulo-Ocular Reflex couples the movement of the eyes to the motion of the head, thereby allowing an organism to keep its gaze fixed in space. This is achieved by causing the motion of the eyes to be equal and opposite to the motion of the head. The VOR control system is typically modelled as a transformation from head velocity to eye velocity. » [Jor.90] cited in [Ber.96]. This solution however has the same disadvantages as the previous one.

- A more behavioural solution consists of applying the techniques described in [Ber.95], the additional tilts are due to the legs and to the terrain being taken into account. An optic flow technique using only a few points in the real or virtual image can be associated with a gyroscope placed on the robot platform to avoid lags.

- On either flat or unstructured terrain, the behavioural solution can be aided by an additional leg variation suppression (pitch suppression).

However, in the behavioural solution, it is necessary to determine the gaze control in both teleoperated and automatic modes where it appears that they are non-trivial problems. They are far beyond the scope of this paper but are the purpose of intensive research in our telepresence design frame. In teleoperated mode it implicitly deals with the interpretation of the operator *intention declaration*. In automatic mode, the gaze control can not be directly derived from previous studies where it is believed that « attention is captured by motion » [Ber.96]. From a camera point of view on a mobile robot, the entire environment is moving.
A relation must be found with the known concept of *visual search* [Wol.94] cited in [Ber.96].

<table>
<tr><td colspan="2">Terrain Types ➡</td><td colspan="2">Flat</td><td>Unstructured</td></tr>
<tr><td colspan="2">Authorised Speeds ➡</td><td>High</td><td>Low</td><td>Low</td></tr>
<tr><td colspan="2">Authorised Locomotion Mode ➡</td><td>Automatic</td><td>Teleoperated or Automatic</td><td>Teleoperated</td></tr>
<tr><td colspan="2">Authorised Teleoperation Mode ➡</td><td>Navigation</td><td>Mission or Navigation</td><td>Mission</td></tr>
<tr><td rowspan="4">Periscopic vision system
(farther vision)</td><td>Variations compensations required</td><td colspan="2">Legs</td><td>Legs + Ground</td></tr>
<tr><td>a) pitch suppression</td><td colspan="2">sufficient</td><td>not sufficient</td></tr>
<tr><td>b) camera platform compensation</td><td colspan="2">better than pitch suppression</td><td>not sufficient</td></tr>
<tr><td>c) horizon tracking</td><td colspan="2">usable and efficient</td><td>usable and efficient</td></tr>
<tr><td rowspan="4">Stereoscopic vision system
(nearer vision)</td><td>Variations compensations required</td><td>not relevant</td><td>Legs</td><td>Legs + Ground</td></tr>
<tr><td>a) pitch suppression</td><td rowspan="3">not relevant</td><td colspan="2">sufficient</td></tr>
<tr><td>b) camera platform compensation</td><td colspan="2">better than pitch suppression</td></tr>
<tr><td>c) object tracking</td><td colspan="2">usable and efficient</td></tr>
</table>

Table 1. Efficiency of the different compensation methods to avoid tilt sickness according to the terrain nature

The behavioural solution seems to be the best to avoid tilt vision sickness. However, the best solution available depends on the nature of the telelocomotion. Table 1 synthesises our research according to the different terrain types and paces. The latter matches the several locomotion modes in teleoperation described in 0.

Roll Sickness Avoidance

To avoid roll of the visual feedback, it is possible to use the same techniques as those analysed for the tilt. However, it must be noted that if a correspondence may be made between the observations in [Gri.87] and vision sickness, it is more relevant in the case of roll than tilt. A. Griffin proposes a method to predict motion sickness in marine or other environments where vertical oscillation occurs at frequencies below 0.5 Hz. We intend to investigate a parallel configuration with horizontal picture oscillations during roll.

Yaw Sickness Avoidance

Taking into account the results of [Per.94] already discussed in section 0, it is important to precisely define the vision system yaw command:

- The periscopic camera must be independently operated in yaw from the robot direction in order to allow anticipation and localisation in the robot world. Depending on the application context, we propose the use of either a high-definition vision helmet or a head tracking system with screen display. However, we insist on the avoidance of ratios other than 1-to-1 between the head motion and the image display movement to suppress the operator disorientation and yaw sickness. Regardless, it must be added that during robot halts, a manual command must permit a horizontal investigation of the world on 360°.

- The stereoscopic video system must be operated by the same interface as the periscopic system, mostly during halts, without forgetting the disconnectable automatic facilities.

Generally, we must retain, too, the solution presented in [Oma.93] to avoid what we called vision sickness: a prediction to smooth the feedback image display derived from the Observer Theory and Kalman filters.

EXPERIMENTS

Experiments are in progress to study the relevance in Telelocomotion of a Behavioural Transform by means of gestures produced by a dedicated optical fibre glove to operate a legged robot in comparison with the use of a joystick. Variance analysis is used to interpret the results. A latin square in experiment protocols provide the order in which the groups of subjects are experiencing the different situations based on different vision feedbacks on a unstructured terrain. Time to perform the tasks and collisions with the real environment are measured.

As human interaction with a machine is often oriented towards application, the teleoperation of a mobile robot under geometrical constraints is not easy to achieve if no training period occurred previously for the operator. A footbridge exists between training and relevant missions or navigation tasks: a real activity with a mobile robot can be prepared in a micro-world – a virtual world or an Augmented Reality world. Pre-tests classify subjects in groups according to their skill level in driving a point on a screen with a joystick.

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